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Study of photosynthetically active radiation and leaf development in a *Salix* energy plantation

Barbara J. Dowsley

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STUDY OF PHOTOSYNTHETICALLY ACTIVE RADIATION AND LEAF DEVELOPMENT IN A *SALIX* ENERGY PLANTATION

by Barbara J. Dowsley

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ABSTRACT

Nilsson's (1983) equation, LA = c•H•D, where LA is shoot leaf area, H is shoot length, D is shoot basal diameter and c is a coefficient, was tested on one year old shoots of Salix alba grown at an experimental energy plantation site in central Newfoundland during July and August 1986. The coefficient (c = 0.67) was derived from destructive measurements of shoot height and diameter, and the equation accurately predicted leaf area during the study period (R^2 = 0.989).

Measurements of photosynthetically active radiation at the plantation site are also presented.

RÉSUMÉ

L'équation de Nilsson (1983) LA = c•H•D•, où LA représente la surface foliaire du rejet, H, sa longueur, D, son diamètre basal, et c, un coefficient, a été contrôlée en juillet et août 1986 avec des rejets de souche d'un an de Salix alba poussant dans une plantation énergétique expérimentale du centre de Terre-Neuve. Le coefficient c = 0,67 a été calculé à partir de mesures de la hauteur et du diamètre obtenues par une méthode destructrice. L'équation a fourni des estimations exactes de la surface foliaire au cours de la période d'étude (R^2 = 0,989).

Des mesures du rayonnement utile à la photosynthèse prises dans la plantation sont également présentées.

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1.0 INTRODUCTION

The Canadian Forestry Service (Newfoundland and Labrador Region) initiated research into the potential of willow (*Salix* spp.) as an agroforestry crop in 1981 (Robertson 1984). Willows provide a high yield at an early age which makes them attractive as a short rotation crop, with the potential of being harvested every two to three years.

The Department of Ecology and Environmental Research at the Swedish University of Agricultural Sciences, Uppsala, Sweden has extensively researched various aspects of the ecology and management of forest biomass production systems, with particular emphasis on the study of *Salix* energy plantations (Perttu 1984). Modelling the potential growth of willows with respect to climatic factors in energy plantation environments has recently received increased attention (Eckersten 1984, Eckersten *et al.* 1983, Nilsson and Eckersten 1983, Perttu *et al.* 1984). The purpose of this research is to predict the potential biomass production of plantations given the influence of radiation and temperature on willow growth. Gross photosynthetic rate for the whole canopy is derived, given estimations of incoming photosynthetically active radiation (400-700 nm) and current leaf area. This rate is combined with an air temperature coefficient, a coefficient representing respiration, and the ratio between above-ground and total biomass, to give an estimation of the growth rate of a willow canopy.

This approach to modelling potential willow growth therefore requires an estimate of current willow leaf area as input to the equation estimating gross photosynthetic rate. Nilsson (1983) demonstrated that the equation:

$$LA = c \cdot H \cdot D$$

gave reasonable estimations of leaf area for one year old shoots of S. viminalis, where LA is leaf area of a shoot, H is shoot length, D is shoot basal diameter, and c is a parameter. Nilsson stresses the practical importance of the equation, given that the shoot height and basal diameter variables can also be used in the non-destructive estimation of stem and leaf dry weight.

This report discusses the applicability of Nilsson's equation in estimating current leaf area of one year old S. alba shoots grown in an energy plantation environment in central Newfoundland during the summer of 1986. Measurements of photosynthetically active radiation at the plantation site are also presented.

2.0 MATERIALS AND METHODS

The study took place at the Canadian Forestry Service's "Glenwood" experimental energy plantation site on the Salmon Pond Forest Access Road, approximately 2 km from the town of Glenwood (48°59'N, 54°53'W). A section of a 2.52 ha cleared area (Fig. 1) was planted with various clones of Salix species during 6-24 May 1985, at a density of approximately six plants per square metre. The trees were cut to ground level during October, 1985.

Figure 1. The Glenwood experimental energy plantation site.

A section of the plantation was chosen for examination on 2? June 1986 where Salix alba plants were present in sufficient numbers to allow for destructive sampling. The area was separated into two plots. The first contained a total of 160 stools in four rows (Fig. 2) and was designated for non-destructive measurements of plant characteristics and measurements of photosynthetically active radiation (PAR). A second plot containing 240 plants (4 rows x 60 plants) was designated for destructive sampling.

Moss and grass were growing abundantly between the rows of trees upon arrival at the field site on 24 June and this was removed by hoe on 1 July. The area between the rows was tilled regularly throughout the growing season.

2.1 Non-destructive Measurements

Total height of all shoots (5-24 shoots per plant) on each of 20 randomly selected stools was measured to the nearest 0.5 cm with a standard tape measure and recorded on a weekly basis from 1 July to 21 August 1986. Diameter of the same shoot at approximately 0.5 cm above where it emerged form the stool (henceforth referred to as basal diameter) was measured to the nearest 0.1 mm using Venier calipers and was recorded on a weekly basis during the study period. The number of nodes (the part of the plant stem where one or more leaves are attached) on each shoot was counted and recorded.

2.2 Destructive Measurements

Ten randomly selected whole plants from the destructive measurement plot were cut to ground level on 11 July, 24 July, 6 August,

Figure 2. The non-destructive measurement plot.

22 August 1986. Height, basal diameter and number of nodes on all shoots (5-27 shoots per plant) were recorded and the leaves removed. The leaves from each shoot were bagged separately, labelled and frozen. The total leaf area (cm^2) of each shoot was analysed during the fall with a LI-COR area measurement system at the Newfoundland Forestry Centre in St. John's.

A regression of height x diameter of each shoot against shoot leaf area was performed with the intercept set to zero, to derive a coefficient to predict shoot leaf area from measurements of height x diameter. The following equation was assumed:

$$LA = c \cdot H \cdot D$$

The above equation was applied using destructive measurements of mean shoot height and diameter per stool. The derived coefficient (c) was used to estimate mean leaf area per shoot. These values were regressed against measured values of mean leaf area per shoot per stool to test the effectiveness of the equation in predicting leaf area given, measurements of height and diameter.

Mean leaf area per shoot per stool was calculated from measurements of mean shoot height and diameter per stool recorded weekly in the non-destructive measurement plot.

2.3 Measurements of Photosynthetically Active Radiation (PAR)

Three LI-COR LI-190SB quantum sensors were tested and calibrated during 1-6 July 1986 at the study site.

A Campbell Scientific 21X data logger was programmed to read the sensors every 30 seconds and calculate five minute averages of PAR

(400-700 nm) in Wm^{-2}. One sensor was was fixed on a 1.5 m post in the non-destructive measurement plot (Fig. 3) to measure total incoming PAR. The position of the two other quantum sensors within the non-destructive measurement plot varied during the study period but were always placed within 10 cm to the north of the base of any given plant (Fig. 4). These sensors measured PAR transmitted through the foliage. Measurements of PAR reflected by the vegetation were recorded for five minutes at various times during the day by inverting a quantum sensor over a plant where transmitted PAR was being measured. PAR measurements were not recorded during wet conditions due to potential damage to the data logger and anticipated inaccuracies of the sensors in the rain.

3.0 RESULTS

3.1 Non-Destructive Measurements

Figure 5 displays the height growth of S. alba plants from 1 July to 21 August 1986. Mean shoot height per stool was calculated from weekly non-destructive measurements of individual shoot heights. Mean height per stool ranged from 18.0 to 37.0 cm on 1 July and the plants grew to a mean height of 43.5 to 81.8 cm on 22 August. Moose began browsing heavily on a number of plants in the non-destructive measurement plot during the week of 10 August (Julian day 222). Although the rate of shoot height growth is decreasing at this time of the season anyway, it is probable that the browsing reduced growth even further.

Figure 3. LI-COR quantum sensor recording incoming photosynthetically active radiation.

Figure 4. LI-COR quantum sensor at the base of a S. alba plant.

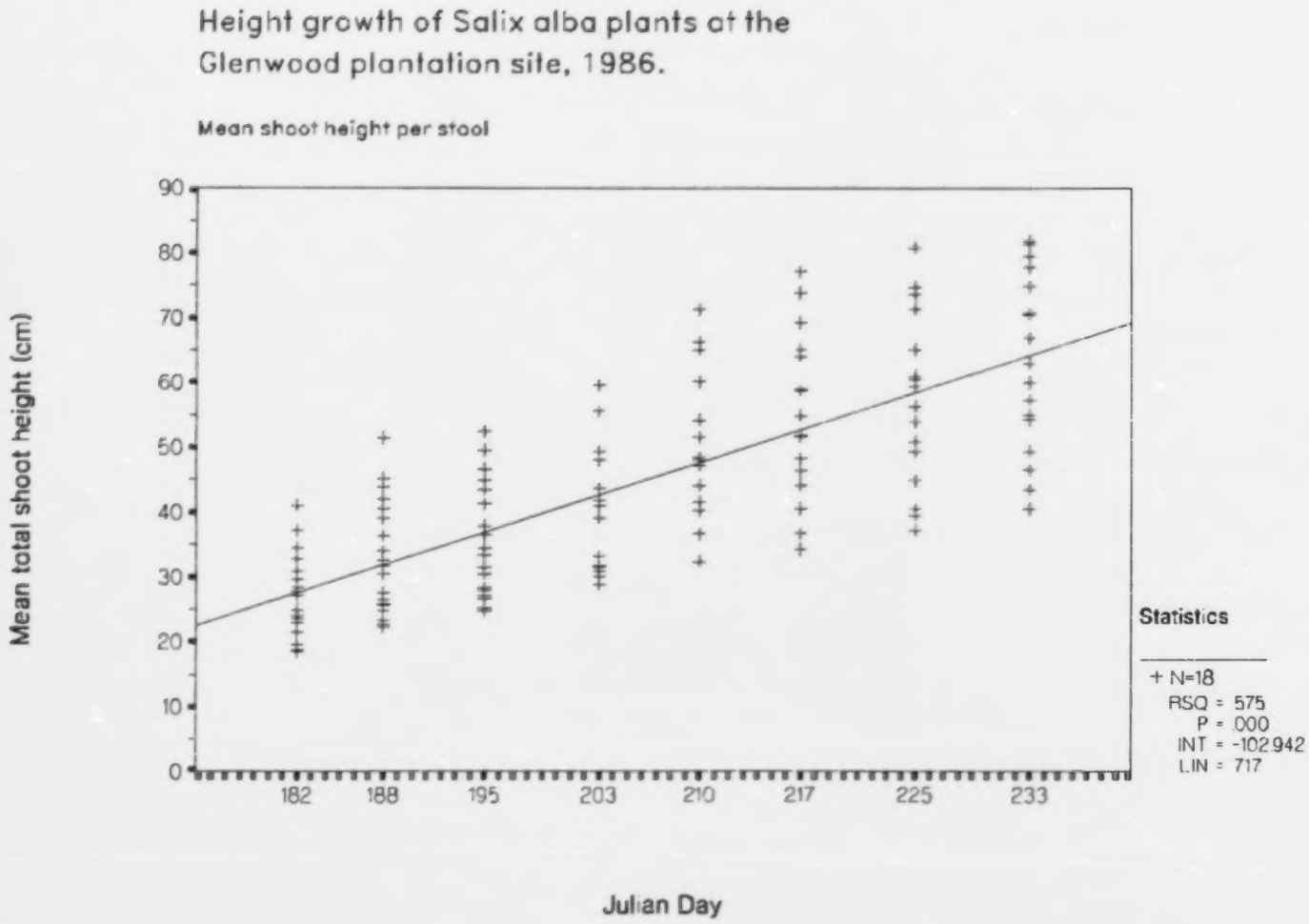

Figure 5. Height growth of Salix alba plants at the Glenwood plantation site, 1986.

Basal diameter growth at the plantation site is displayed in Figure 6. Mean basal diameter per stool increased from 2.3 to 3.6 mm on 1 July to 3.2 to 5.9 mm on 22 August.

The mean number of nodes per shoot throughout the study period is displayed in Figure 7. This measurement is indicative of the steady increase in the number of leaves per shoot until 13 August (Julian day 225) when the effect of the browsing by moose would have lowered the number of leaves on the taller shoots.

3.2 Destructive Measurements

Measurements of shoot height, shoot diameter, number of nodes and leaf area recorded from plants harvested on 11 July, 25 July, 6 August and 22 August are contained in Appendix A. The regression of height x diameter against measured leaf area per shoot derived a coefficient (c) value of 0.67. The predictive equation for leaf area per shoot is therefore:

$$LA = 0.67 \cdot H \cdot D \qquad R^2 = 0.971$$

Figure 8 displays the results of the regression of measured mean leaf area per shoot versus calculated mean leaf area per shoot. The line represents $y = x$. The equation appears to predict mean leaf area per shoot accurately ($R^2 = 0.989$), particularly for relatively low values of leaf area (less than 100 cm^2).

Mean leaf area per shoot per stool calculated from measurements of height and diameter recorded weekly in the non-destructive plot is displayed in Figure 9. Leaf area increased steadily throughout the study period.

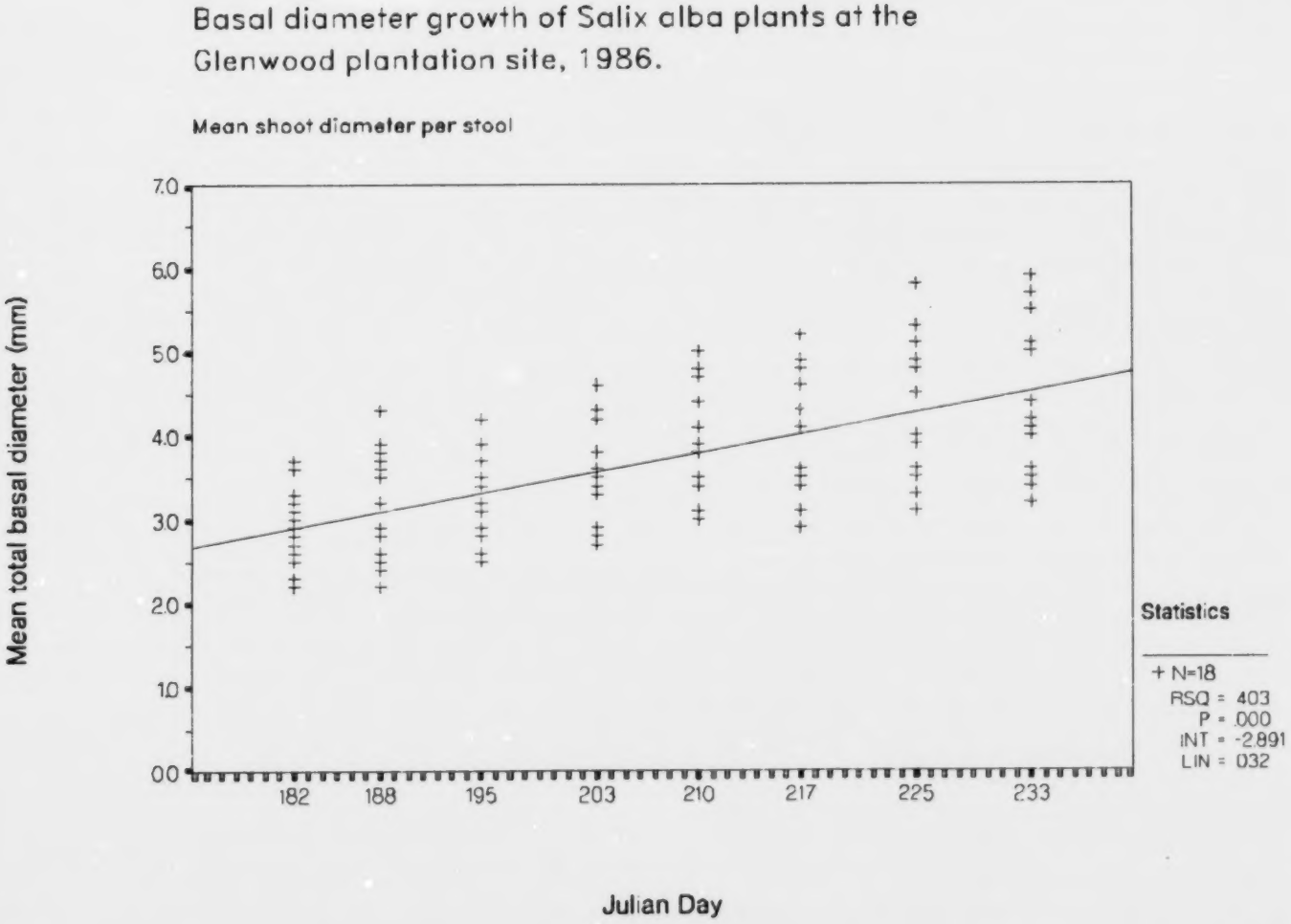

Figure 6. Basal diameter growth of Salix alba plants at the Glenwood plantation site, 1986.

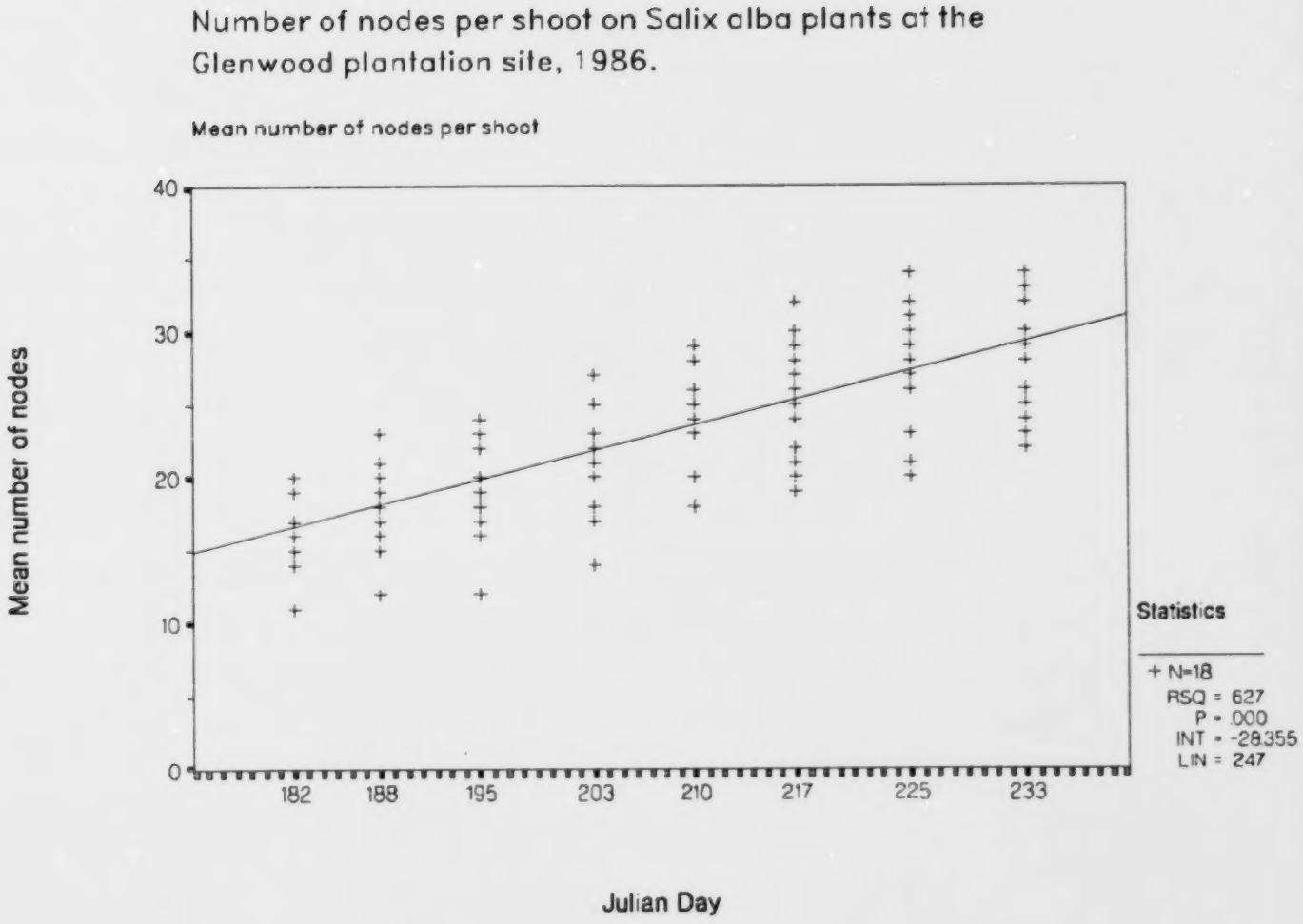

Figure 7. Number of nodes per shoot on *Salix alba* plants at the Glenwood plantation site, 1986.

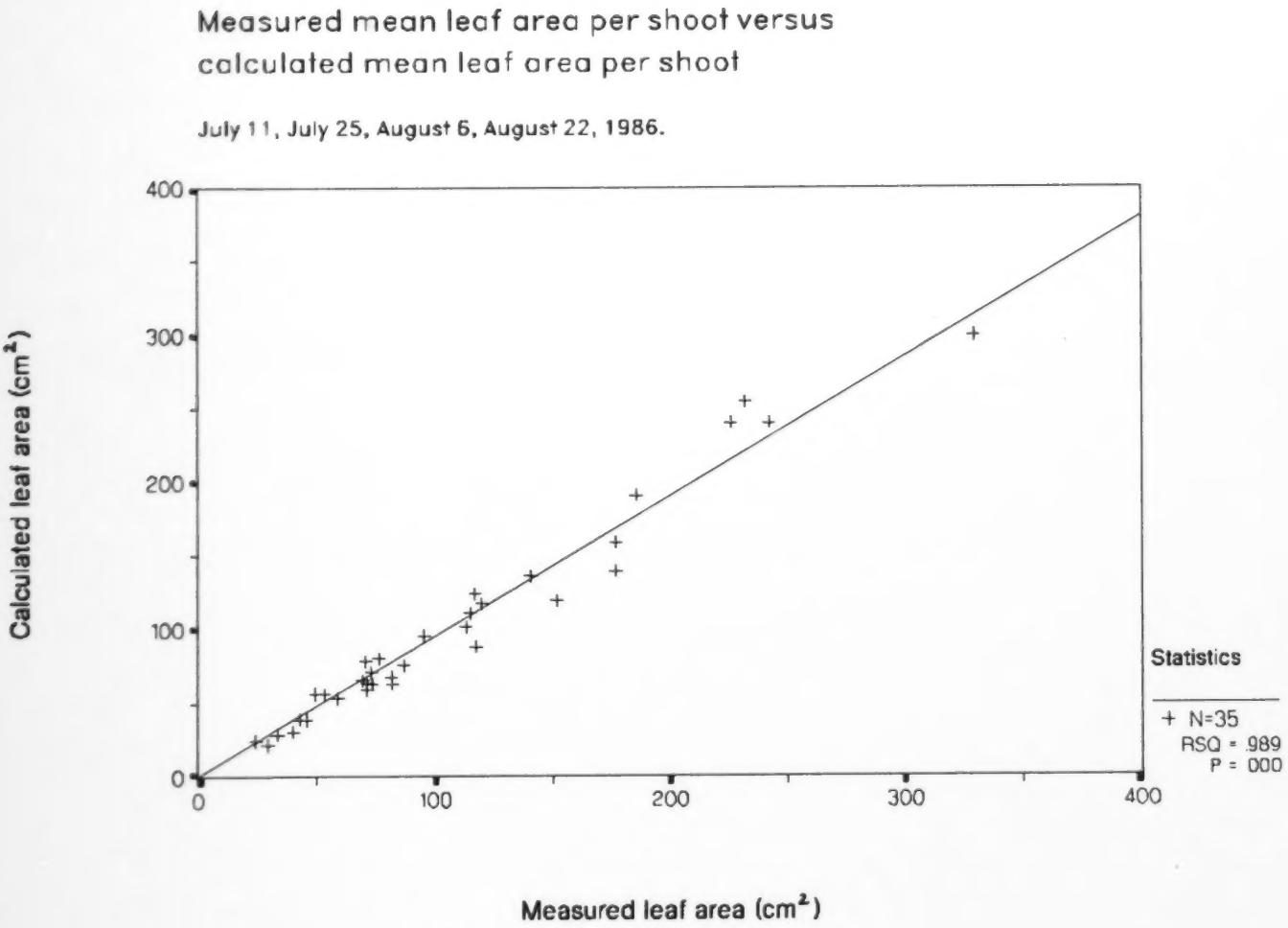

Figure 8. Measured mean leaf area per shoot versus calculated mean leaf area per shoot.

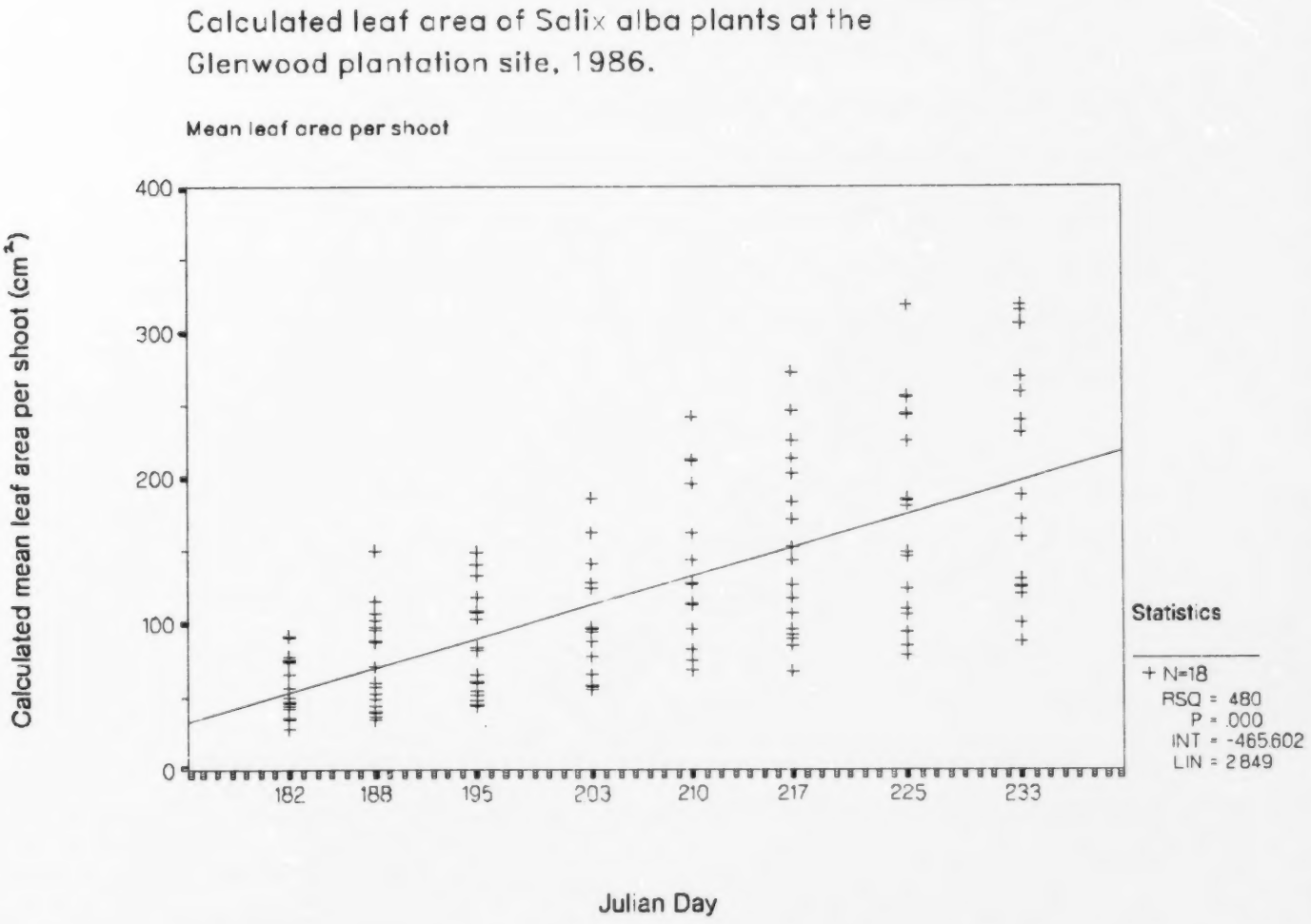

Figure 9. Calculated leaf area of Salix alba plants at the Glenwood plantation site, 1986.

3.3 Measurements of Photosynthetically Active Radiation (PAR)

PAR measured in the non-destructive measurement plot on 23 July is displayed in Figure 10. Predominantly overcast conditions prevailed until 13:00 hours NDST followed by sunny periods with intermittent clouds for the remainder of the day. Total incoming PAR (above canopy) peaked at 14:00 hours NDST and decreased steadily after 16:00 hours. Low amounts of PAR were still detectable at 21:00 hours and PAR was zero by 22:00 hours. Measurements of PAR transmitted through the foliage (below canopy a and b) increased steadily until 10:00 hours and then remained relatively constant throughout the day until 18:00 hours when it decreased rapidly. At 21:00 hours only low amounts of PAR were detected. PAR reflected by the foliage ("reflected" in Fig. 10) from 12:00 to 18:00 hours remained below 30 Wm^{-2}.

The sky conditions on 24 July were sunny with cloudy periods. Figure 11 displays PAR recorded on this day. PAR measured above the canopy again reached its maximum at 14:00 hours NDST. PAR transmitted below the canopy was approximately 50% of total incoming PAR for most of the day. PAR reflected by the foliage at 13:00, 14:00 and 15:00 hours remained constant during this period.

Total incoming PAR measured on 28 July (Fig. 12) increased steadily from sunrise until 11:00 hours, and peaked at 16:00 hours. After this time PAR decreased rapidly until sunset. PAR measured above the canopy varied between 11:00 and 16:00 hours, fluctuating slightly on an hourly basis. July 28 was again sunny with cloudy periods. PAR measured below the canopy did not show the same marked variation at mid-day,

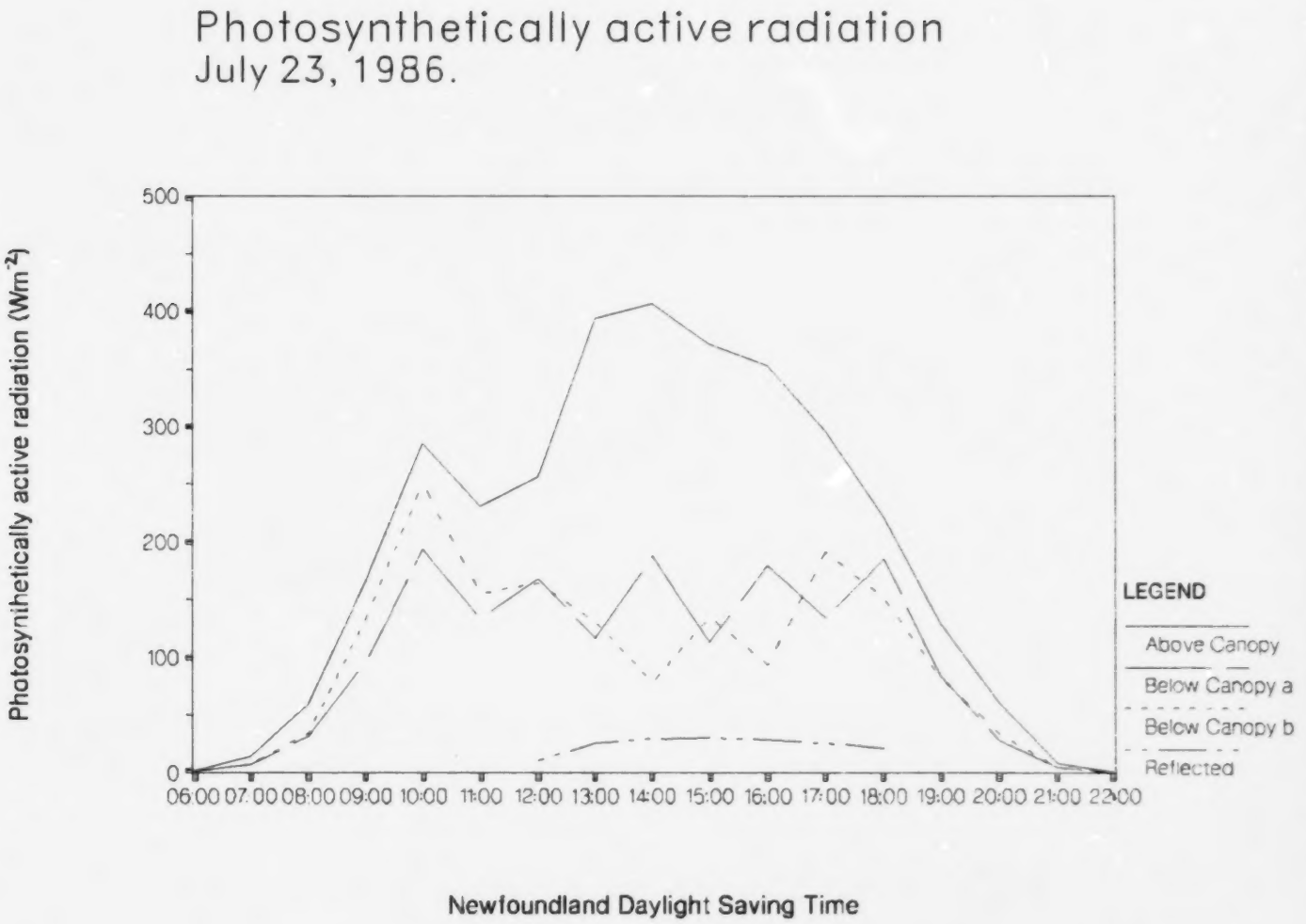

Figure 10. Photosynthetically active radiation 23 July 1986.

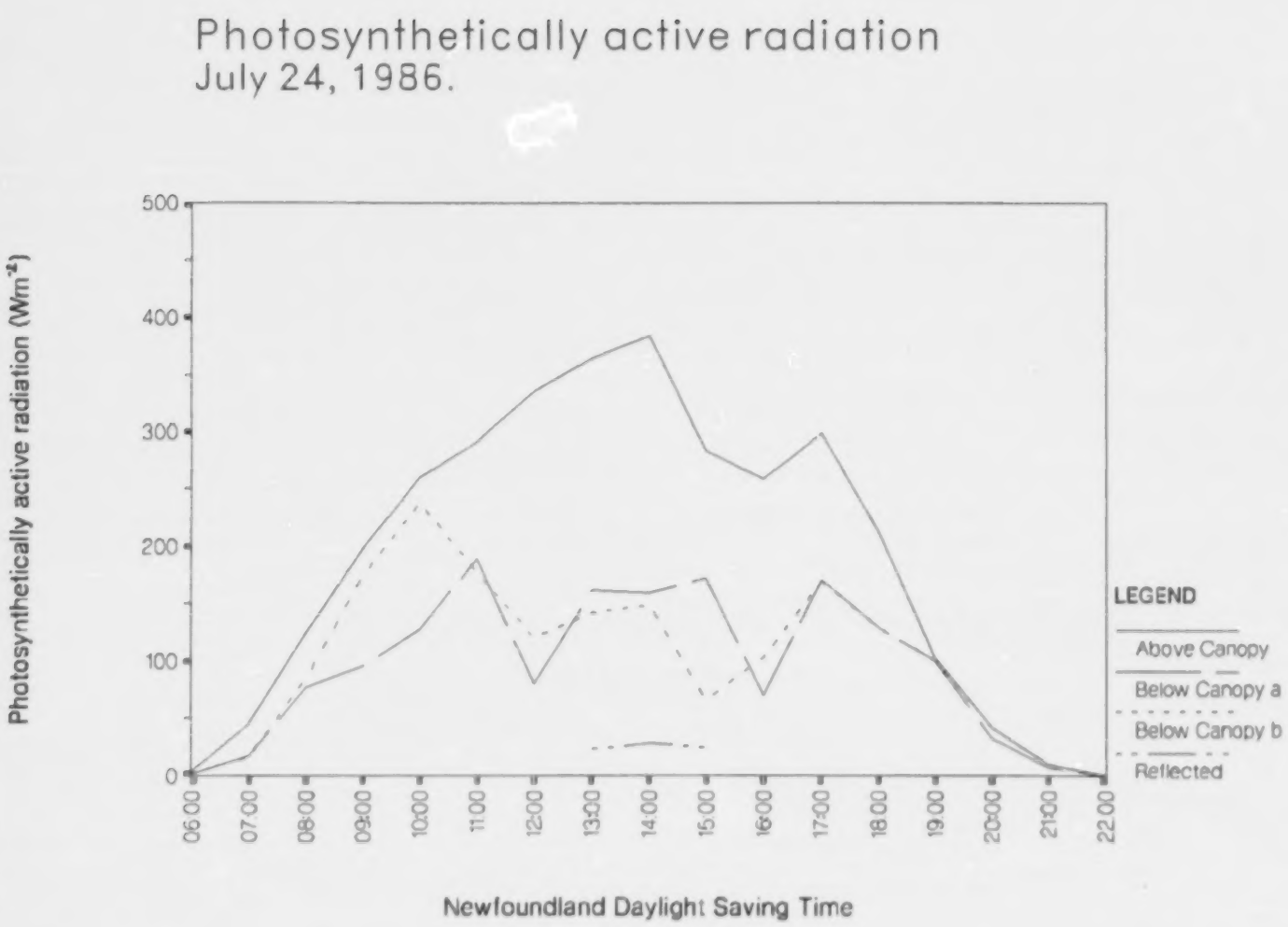

Figure 11. Photosynthetically active radiation 24 July 1986.

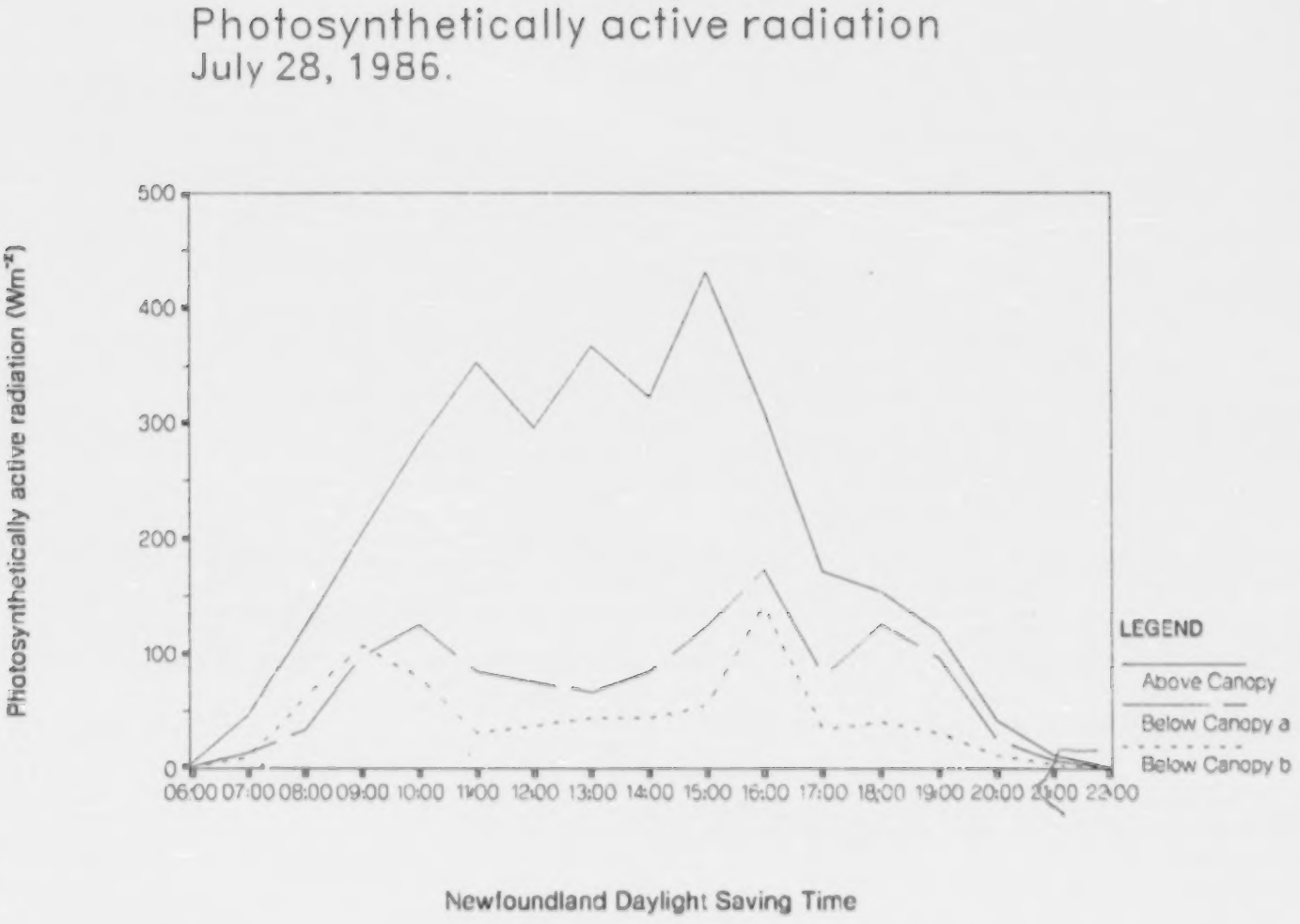

Figure 12. Photosynthetically active radiation 28 July 1986.

yet decreased slightly between 11:00 and 14:00 hours. PAR transmitted through the canopy also peaked at 16:00 hours.

Figure 13 displays measurements of PAR from 06:00 to 13:00 hours NDST on 29 July. The day was overcast with light precipitation falling during the measurement period. Heavy rain began at 13:00 hours and therefore no measurements were recorded after this time. Total incoming PAR and PAR transmitted to below the canopy were greatly reduced due to the overcast conditions. PAR measured above the canopy remained under 200 Wm^{-2} during the hours it was measured. Reflected PAR measured at 10:00, 11:00, 12:00 and 13:00 hours remained under 20 Wm^{-2}.

Clear and sunny conditions prevailed on 5 August (Fig. 14). Total incoming PAR was at its maximum between 12:00 and 14:00 hours and PAR transmitted through the foliage was approximately 30% of total incoming PAR. PAR reflected by the canopy was below 15% of total incoming PAR.

Figure 15 displays measurements of PAR on 6 August. Weather conditions were overcast with light precipitation until 11:30 hours, with intermittent sunny breaks for the remainder of the day. PAR measured above the canopy increased rapidly after 11:00 hours when conditions cleared and peaked at 14:00 hours. PAR measured below the canopy also increased with the change in sky conditions at 11:30 hours and fluctuated slightly until 17:00 hours. Measurements of PAR above and below the canopy decreased steadily after 17:00 hours. PAR reflected by the canopy varied little between 12:00 and 18:00 hours.

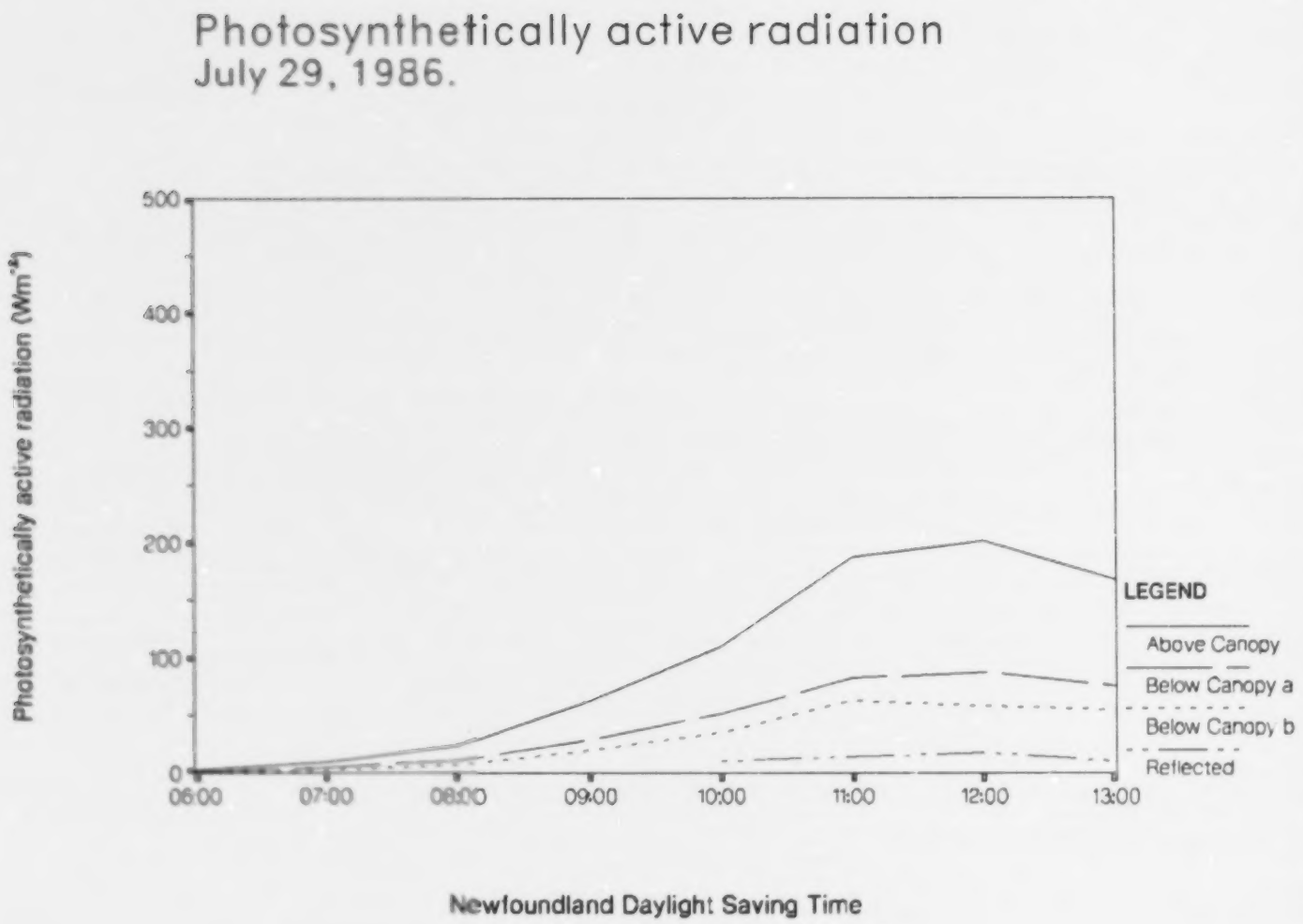

Figure 13. Photosynthetically active radiation 29 July 1986.

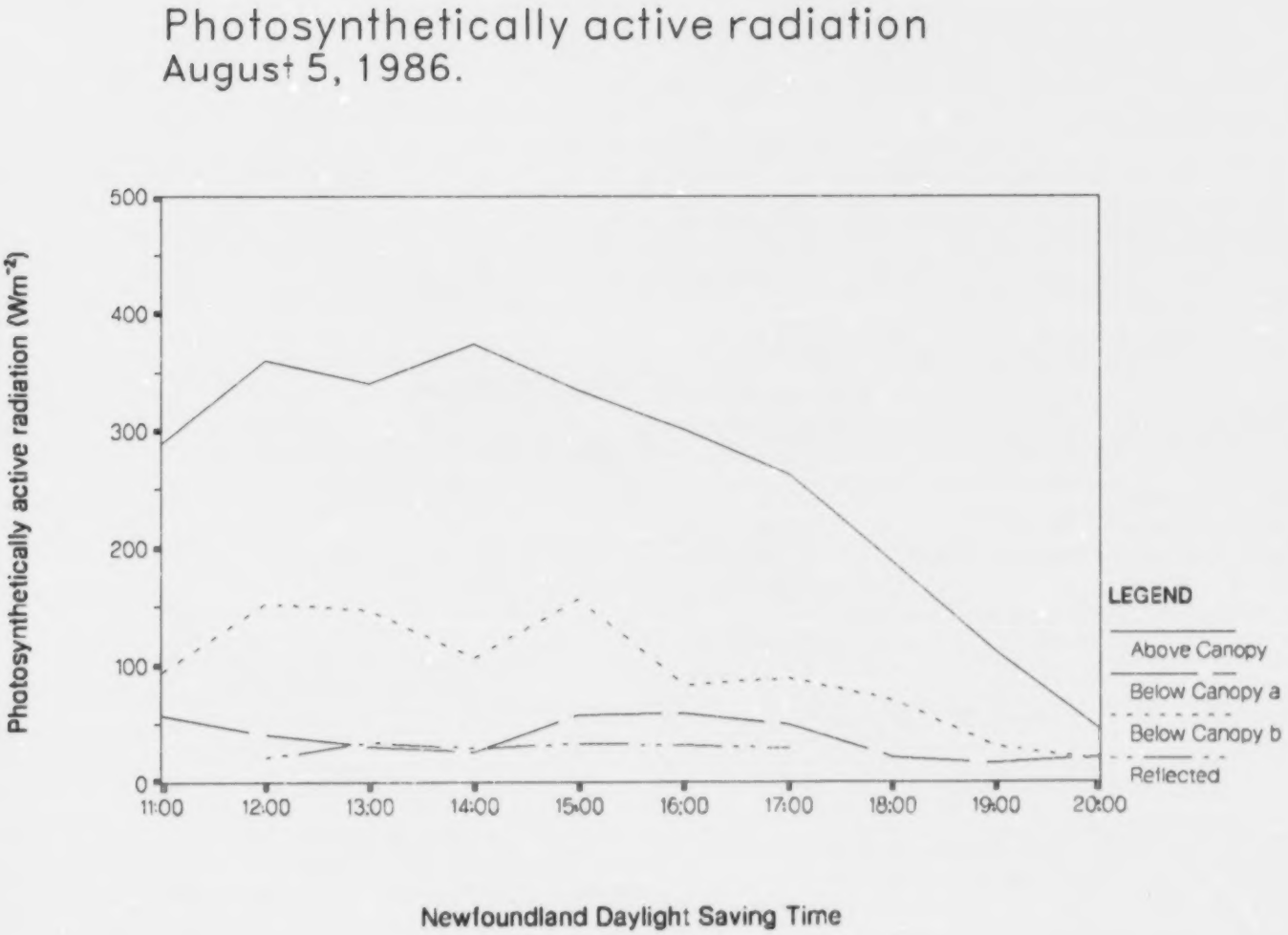

Figure 14. Photosynthetically active radiation 5 August 1986.

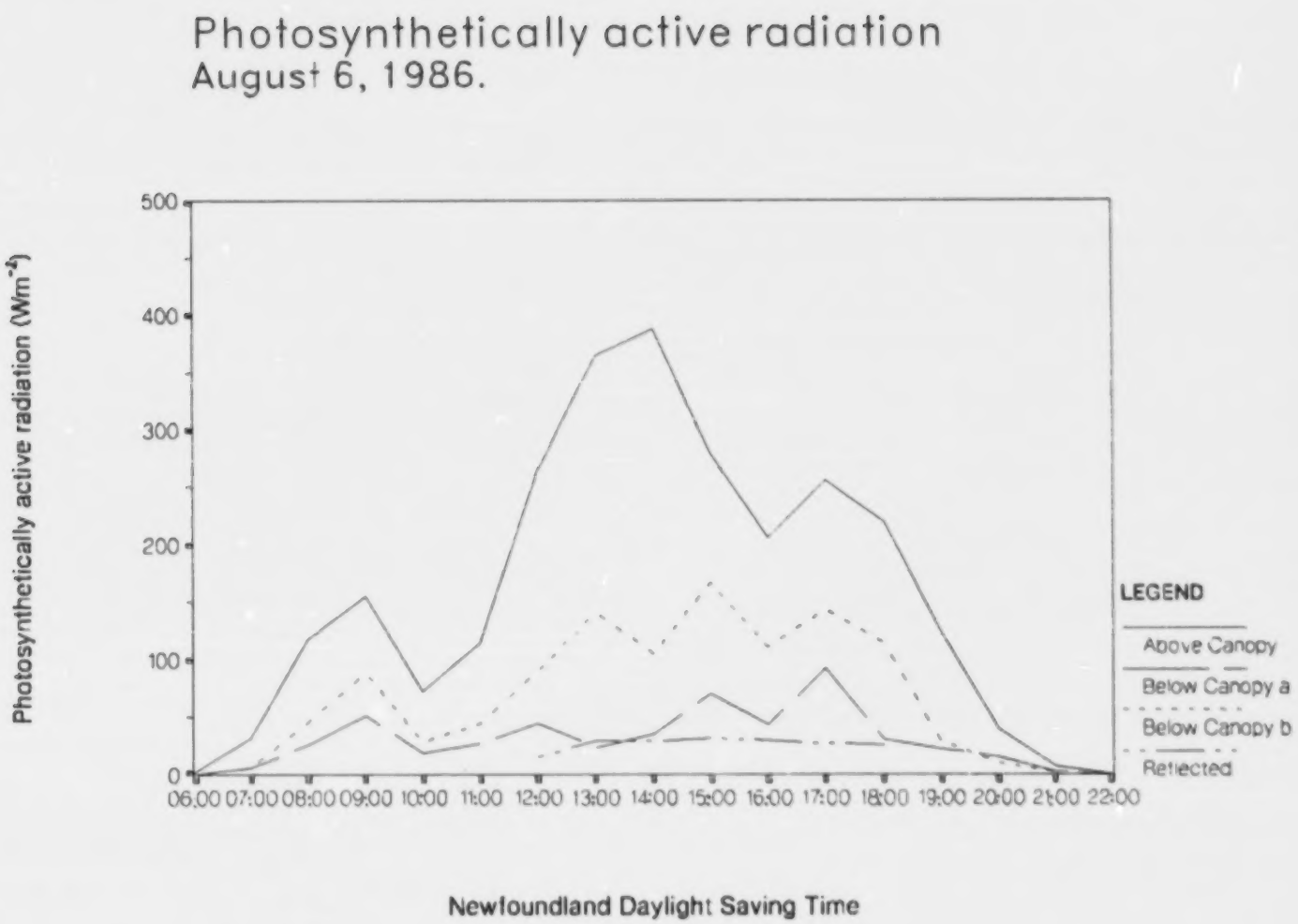

Figure 15. Photosynthetically active radiation 6 August 1986.

4.0 DISCUSSION AND CONCLUSIONS

Height and basal diameter growth of S. alba plants at the Glenwood plantation site in 1986 was commensurable for Salix plants in their first season of growth following establishment year. The 1987 growing season will likely result in increased growth considering that the root systems of these plants will be further developed, and therefore, a greater accumulation of above-ground biomass is anticipated. The browsing by moose likely continued after the 1986 study period and this would obviously have had a detrimental effect on overall growth for the whole season. The number of nodes increased steadily from 1 July to 22 August, indicating that new leaves were continually being produced during this time. Estimates of mean leaf area per shoot on a weekly basis in the non-destructive measurement plot suggest a steady increase during the study period.

Nilsson's equation (1983), $LA = c \cdot H \cdot D$, with $c = 0.67$, proved an effective method for estimating leaf area of one year old S. alba shoots at the Glenwood plantation site from 1 July to 22 August 1986. The equation would probably be less effective in predicting leaf area during the early and late parts of the growing season as Nilsson (ibid) determined that his equation predicted leaf area most accurately during August and September in Sweden.

This method of using non-destructive measurements of shoot length and basal diameter to predict leaf area is recommended for future

studies where an estimation of Salix spp. leaf area is required. Destructive sampling of shoots should take place at approximately three week intervals throughout the entire growing season.

Incoming photosynthetically active radiation at the Glenwood plantation site typically reached maximum values at 14:00 hours NDST under clear and partially cloudy conditions. Overcast conditions may reduce potential incoming PAR by as much as 50%. No conclusions can be drawn with respect to PAR transmitted below the canopy as only two sensors were used to measure these values, and therefore the results would not reflect the spatial variation within the measurement plot. It would be desirable to make measurements of transmitted PAR in a more mature plantation since the trees at the Glenwood site were not advanced enough to give significant estimations of the percentage of total incoming PAR absorbed by the canopy when two sensors were used. PAR reflected by individual plants was approximately 10% of total incoming PAR between 10:00 and 18:00 hours on most days.

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Appendix A

Destructive Measurements					
Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
192	1	39.0	2.7	15	71.8
	1	37.5	2.5	16	78.0
	1	28.5	2.2	15	50.6
	1	53.0	4.5	**	129.9
	1	67.0	6.0	27	269.7
	1	42.0	3.6	23	130.7
	1	18.0	1.8	**	35.3
	1	45.0	3.5	20	101.2
	1	59.5	4.6	23	193.9
	1	49.0	4.1	24	163.9
	1	38.0	3.5	23	104.6
	1	45.5	3.9	22	152.7
	1	67.5	5.8	25	234.9
	1	32.0	3.4	23	95.1
	1	11.0	1.7	11	19.9
	1	25.0	2.7	17	54.9
	1	61.5	6.0	25	174.8
	1	11.0	2.4	15	43.5
	1	33.0	2.7	17	73.2
	2	45.5	4.1	23	152.9
	2	44.0	3.6	20	109.2
	2	44.0	4.1	23	111.2
	2	24.0	2.2	19	52.9
	2	49.0	3.9	27	155.1
	2	25.0	2.4	19	60.1
	2	24.0	2.2	16	46.6
	2	44.0	4.3	20	139.2
	2	32.0	3.2	25	77.5
	2	11.5	1.4	12	12.0
	2	20.0	2.1	14	41.0
	2	30.5	2.6	21	68.2
	2	27.5	2.5	17	50.6

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
192	2	21.5	2.0	15	44.2
	2	16.0	1.5	12	23.9
	2	7.0	2.4	15	38.7
	2	5.5	2.3	8	27.9
	3	46.0	4.4	24	143.6
	3	36.5	3.5	22	102.5
	3	32.0	3.0	16	61.3
	3	17.0	2.1	15	32.7
	3	39.0	3.4	21	109.1
	3	41.0	3.5	23	123.6
	3	31.0	2.7	16	90.9
	3	39.0	4.5	25	114.6
	3	37.0	3.6	20	96.8
	3	16.0	1.7	12	25.8
	3	21.5	2.5	19	35.4
	3	17.5	2.0	15	44.2
	3	17.0	1.6	12	21.6
	3	13.0	1.7	13	23.4
	4	14.5	2.2	16	28.6
	4	8.5	1.1	11	12.2
	4	30.5	2.8	21	75.7
	4	16.0	2.0	14	29.5
	4	12.0	2.0	12	20.7
	4	7.5	1.1	10	10.3
	5	34.0	3.3	18	95.3
	5	37.5	4.1	18	86.7
	5	38.0	3.8	20	106.7
	5	23.0	2.3	15	53.8
	5	40.0	4.1	19	101.6
	5	27.0	2.8	17	63.3
	5	29.0	2.8	18	57.5
	5	27.0	2.8	18	63.8
	5	25.0	2.4	17	58.0

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
192	5	13.5	1.3	12	26.6
	6	32.0	3.1	16	44.3
	6	36.0	3.7	19	93.1
	6	40.0	3.5	22	107.7
	6	31.0	3.3	19	86.7
	6	6.0	0.8	10	8.7
	6	17.0	1.6	12	22.5
	6	36.5	4.0	**	93.4
	6	30.0	3.1	19	79.0
	6	27.0	2.6	18	30.3
	6	18.0	1.9	15	66.8
	6	8.0	1.4	10	14.0
	7	28.5	2.8	19	62.7
	7	32.0	3.0	18	59.9
	7	32.0	3.4	21	79.5
	7	23.0	2.7	17	44.5
	7	22.5	2.4	17	54.3
	7	22.0	2.8	19	60.6
	7	15.0	1.9	15	28.5
	7	14.0	1.9	14	26.0
	7	18.0	1.9	15	24.0
	7	8.0	1.7	13	16.6
	9	17.0	1.9	12	34.3
	9	19.0	2.9	19	47.1
	9	18.0	1.7	14	31.2
	9	26.5	3.0	18	65.4
	9	33.0	3.4	19	82.1
	9	26.0	2.8	13	55.0
	9	10.5	1.9	14	22.0
	9	7.0	1.3	9	18.6
	9	23.0	2.7	14	51.4
	9	4.0	0.7	5	11.2
	9	16.5	2.0	13	30.1

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
192	9	13.0	1.7	12	28.3
	9	11.0	1.5	14	23.7
	9	25.0	3.2	18	64.1
	10	25.5	2.7	19	49.4
	10	16.0	2.1	16	24.9
	10	17.0	2.2	17	33.3
	10	17.0	2.1	17	27.9
	10	17.5	2.0	16	32.4
206	1	58.5	3.6	25	167.2
	1	26.0	3.1	20	68.3
	1	35.5	2.5	19	76.4
	1	52.0	4.1	27	151.3
	1	13.0	1.5	10	31.2
	1	33.5	3.1	19	67.0
	1	38.0	3.4	23	77.6
	1	71.0	5.0	32	239.8
	1	56.5	4.6	28	184.3
	1	60.5	4.4	26	172.5
	1	28.0	2.5	16	50.8
	1	52.0	4.8	22	129.2
	1	54.0	4.6	28	188.0
	1	88.0	7.2	33	399.9
	1	64.0	4.6	29	207.2
	1	50.0	3.2	24	135.8
	1	37.0	3.4	24	92.7
	1	49.0	3.5	27	144.2
	1	23.5	2.2	17	52.9
	1	65.0	4.8	28	206.5
	1	16.5	2.0	14	40.6
	1	73.5	5.6	30	260.8
	1	68.0	5.5	30	221.2
	1	45.0	3.1	25	127.9
	1	37.0	3.1	21	90.7

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
206	1	39.0	2.7	20	79.7
	1	52.0	3.6	24	136.4
	2	34.0	3.0	19	81.5
	2	28.0	2.6	18	52.4
	2	55.0	4.8	26	192.8
	2	38.5	3.6	25	100.0
	2	39.5	3.6	19	76.3
	2	12.5	1.6	12	19.1
	2	13.0	1.8	13	20.4
	2	13.0	1.6	12	18.5
	2	31.0	2.5	20	63.1
	3	38.5	4.3	20	88.0
	3	21.5	2.5	14	42.0
	3	6.0	1.2	8	9.2
	3	35.5	4.0	21	84.4
	3	24.5	2.8	15	46.1
	3	11.0	1.7	8	16.8
	3	10.5	1.7	8	18.6
	3	20.0	2.5	13	42.3
	3	12.0	1.7	10	21.8
	3	50.5	5.6	23	127.2
	4	59.5	5.4	26	158.5
	4	37.5	3.2	20	62.8
	4	43.5	4.0	23	121.1
	4	47.5	4.1	24	109.6
	4	49.0	3.4	22	107.3
	4	39.0	3.6	21	75.8
	4	43.0	3.4	22	101.8
	4	16.5	1.6	17	26.7
	4	44.0	3.6	23	106.0
	4	33.0	2.5	19	67.6
	4	31.0	2.7	16	62.5
	4	27.5	2.5	16	57.8

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
206	4	27.0	2.5	16	59.6
	4	22.5	2.5	14	44.1
	4	20.0	1.8	13	26.7
	4	24.0	1.9	15	30.9
	5	31.5	2.9	20	63.6
	5	25.5	2.2	18	51.7
	5	29.0	3.2	19	58.4
	5	18.0	2.2	14	30.5
	5	19.0	2.2	17	39.8
	5	17.0	2.4	16	29.1
	5	16.5	2.2	13	27.2
	6	62.0	4.9	30	213.4
	6	70.0	5.5	27	206.5
	6	36.5	3.1	19	60.8
	6	46.0	4.9	22	149.0
	6	55.0	3.8	27	154.0
	6	20.5	2.4	15	40.8
	6	39.0	3.1	21	98.1
	6	56.0	5.6	25	145.1
	6	49.0	3.6	23	117.2
	6	32.0	3.0	18	62.9
	6	36.0	3.0	21	86.6
	6	31.0	2.5	17	67.8
	6	32.0	2.5	19	71.6
	6	27.0	2.4	18	56.1
	6	24.5	2.4	16	45.5
	6	35.5	3.3	19	77.5
	6	32.0	2.7	17	78.0
	6	23.5	2.0	17	46.7
	6	18.0	2.1	13	32.9
	7	50.0	4.3	24	112.6
	7	52.0	4.4	21	123.6
	7	47.0	4.0	**	146.1

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
206	7	20.0	2.8	18	42.3
	7	17.5	1.8	11	23.9
	7	19.0	2.1	11	21.0
	7	19.0	2.4	11	25.5
	8	33.5	3.8	21	70.3
	8	34.0	3.4	20	61.4
	8	33.5	3.8	18	78.4
	8	27.0	2.8	18	53.4
	8	23.0	2.5	15	45.7
	8	22.5	2.3	17	47.9
	8	13.0	1.4	11	16.9
	9	20.0	2.4	14	37.9
	9	12.0	1.6	12	17.0
	9	15.5	2.0	13	22.4
	9	18.5	2.4	13	28.0
	9	17.0	2.0	13	20.3
	9	19.0	2.1	14	26.3
	9	19.0	2.2	14	23.8
	9	15.0	1.9	13	19.7
218	3	85.0	5.9	35	330.6
	3	68.0	4.9	32	218.5
	3	81.0	5.1	34	298.6
	3	58.0	4.2	27	173.0
	3	66.0	4.8	34	253.1
	3	50.0	3.4	27	150.1
	3	67.0	4.9	31	238.0
	3	37.0	2.4	20	86.7
	3	35.0	2.6	15	63.7
	3	49.5	3.8	27	146.0
	3	27.5	3.0	17	75.4
	3	26.5	2.4	19	56.1
	4	53.0	3.6	24	137.9
	4	55.0	3.7	24	140.0

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
218	4	47.0	3.4	23	114.9
	4	38.5	3.4	21	73.7
	4	47.0	3.4	23	56.8
	4	33.0	2.5	16	120.4
	4	43.5	3.6	22	100.3
	4	70.0	5.5	26	189.1
	4	48.5	3.8	24	109.6
	4	36.0	3.0	19	79.6
	4	57.5	3.6	25	152.5
	4	53.5	4.1	23	128.5
	5	41.0	3.7	25	114.8
	5	35.0	3.1	16	93.8
	5	34.0	3.0	20	83.4
	5	31.0	3.0	21	74.6
	5	62.0	5.0	28	259.4
	5	23.0	2.0	18	50.9
	5	24.5	2.1	18	55.6
	5	12.0	1.5	14	26.3
	5	13.0	1.7	11	27.4
	5	13.5	1.9	14	31.4
	6	59.5	4.3	31	190.2
	6	88.5	6.1	37	353.8
	6	89.0	6.9	37	398.3
	6	81.0	6.0	36	321.5
	6	36.0	3.1	25	91.9
	6	32.0	2.7	20	72.9
	6	75.5	5.0	35	267.6
	7	46.0	3.1	20	101.3
	7	30.5	2.8	21	56.6
	7	56.5	3.7	25	156.0
	7	52.5	3.7	26	110.3
	7	54.5	3.5	**	120.3
	7	51.5	3.7	25	134.1

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
218	7	41.5	3.1	20	90.2
	7	58.5	3.9	27	149.1
	7	41.0	3.0	19	93.0
	7	58.0	4.4	25	141.0
	7	43.0	3.3	22	99.4
	7	61.0	4.2	25	166.2
	7	60.0	4.1	27	167.8
	7	44.0	3.1	22	117.3
	7	40.5	2.7	20	82.9
	7	61.5	4.3	28	178.2
	7	45.0	3.1	20	110.1
	7	40.0	2.7	19	93.0
	7	43.0	3.0	21	107.0
	8	75.0	5.7	28	307.3
	8	73.5	5.2	26	247.7
	8	69.5	5.3	25	217.7
	8	61.5	4.4	27	201.0
	8	31.0	2.6	16	62.9
	8	43.0	3.1	18	89.1
	8	18.0	1.7	16	43.4
	8	41.5	3.2	22	122.5
	8	19.0	2.1	13	40.5
	8	11.0	1.7	16	29.8
	8	52.0	4.2	21	139.7
	8	43.5	3.2	27	126.3
	8	25.0	2.2	18	64.0
	8	24.0	1.8	19	62.0
	8	42.0	3.7	25	108.6
	8	24.0	2.5	16	52.6
	8	31.0	2.4	17	65.4
	8	26.5	2.1	17	52.8
	9	60.0	4.6	26	203.8
	9	39.0	3.1	22	100.9

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
218	9	33.5	2.6	18	74.2
	9	43.0	3.6	23	111.0
	9	37.5	3.1	20	81.9
	9	36.0	2.8	19	75.1
	9	28.5	2.8	19	63.5
	9	42.0	3.3	22	115.9
	9	26.5	2.3	18	52.6
	9	38.0	3.1	20	88.3
	9	28.5	2.5	19	61.9
	9	31.0	2.9	18	65.3
	9	24.0	2.3	15	50.7
	9	32.0	2.7	19	66.6
	10	59.0	4.4	29	208.1
	10	52.5	3.7	27	170.2
	10	49.5	3.8	25	156.6
	10	37.5	3.2	23	131.9
	10	29.0	2.8	18	92.9
	10	15.5	1.6	13	22.5
	10	22.0	1.7	14	38.6
234	1	80.0	5.8	33	285.5
	1	63.0	4.5	29	218.1
	1	93.0	6.3	37	405.6
	1	82.5	5.3	38	379.7
	1	51.0	3.7	26	138.6
	1	65.5	3.7	28	182.1
	1	120.0	8.1	41	893.4
	1	61.0	3.8	26	173.3
	1	84.0	5.3	33	294.5
	1	102.0	7.1	37	438.0
	1	63.5	4\.2	32	213.6
	2	113.0	8.6	43	573.4
	2	58.5	3.5	26	149.8
	2	84.0	5.4	35	262.6

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
234	2	118.0	7.5	43	504.0
	2	67.0	4.3	32	227.1
	2	75.0	5.2	34	234.5
	2	69.5	5.2	33	206.7
	2	39.0	3.4	24	117.4
	2	44.5	3.4	25	110.8
	2	57.5	4.0	29	173.3
	2	66.0	4.4	30	197.0
	2	70.5	5.0	35	208.3
	2	86.0	5.0	32	259.2
	2	53.0	3.4	23	123.6
	2	69.5	4.9	31	208.2
	2	57.0	3.7	29	150.0
	2	65.0	4.1	30	186.9
	2	57.5	3.8	27	170.9
	3	57.5	3.6	27	184.8
	3	80.0	4.9	34	269.8
	3	46.5	3.3	21	79.0
	3	96.0	6.0	39	432.7
	3	42.5	3.2	23	97.5
	3	64.0	3.7	28	172.2
	3	47.5	2.9	22	109.1
	3	83.0	5.5	36	227.8
	3	77.0	5.2	31	218.1
	3	75.5	4.8	32	227.3
	3	62.5	4.2	30	192.6
	3	79.5	5.5	35	241.6
	3	52.5	3.6	27	137.9
	3	52.0	3.5	23	137.3
	3	30.5	2.6	20	58.4
	4	46.0	3.5	24	111.9
	4	58.5	4.2	27	130.8
	4	28.0	2.3	20	57.3

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
234	4	35.0	2.9	21	72.8
	4	21.0	2.0	14	37.1
	4	32.0	2.4	18	53.6
	4	54.0	3.9	26	128.0
	4	42.5	3.4	24	98.0
	4	39.5	3.1	23	83.0
	4	29.0	2.4	19	57.9
	4	33.0	2.4	20	66.8
	4	28.0	2.0	19	52.3
	4	36.5	2.7	20	77.4
	4	31.0	2.6	21	60.6
	4	30.5	2.4	19	57.6
	4	17.5	1.7	13	30.4
	4	37.0	3.0	20	66.9
	5	90.0	6.2	43	340.4
	5	77.0	5.3	39	274.6
	5	92.0	6.4	38	328.1
	5	85.0	6.0	38	321.5
	5	60.5	4.5	35	149.2
	5	87.0	5.9	40	344.0
	5	79.0	5.3	35	260.7
	5	66.0	4.4	34	193.0
	5	53.0	4.6	30	143.0
	5	52.5	3.5	28	123.3
	5	38.5	3.3	25	74.9
	6	77.5	5.0	31	241.6
	6	75.0	4.8	32	239.4
	6	31.5	2.4	18	74.9
	6	32.0	2.2	18	60.3
	6	31.5	3.4	19	59.8
	6	29.0	3.5	16	52.2
	6	36.5	2.1	17	65.6
	6	70.0	4.6	28	223.4

Appendix A (Cont'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
234	6	51.0	3.4	24	114.3
	6	45.0	3.5	23	99.0
	6	101.0	7.3	**	717.4
	7	24.0	2.1	17	43.3
	7	33.5	2.7	24	86.2
	7	72.0	4.6	31	246.7
	7	84.0	5.2	35	401.4
	7	21.5	2.1	18	46.3
	7	36.0	2.7	24	86.7
	8	51.0	3.6	29	150.2
	8	84.5	5.6	36	404.4
	8	73.0	4.7	32	313.5
	8	79.5	5.1	35	270.9
	8	33.5	2.8	20	92.1
	8	42.0	2.8	25	120.5
	8	42.5	2.5	24	110.4
	8	26.5	2.0	17	60.9
	8	28.5	2.5	21	68.9
	9	46.5	3.5	25	112.0
	9	35.0	2.4	18	78.6
	9	54.0	3.5	25	132.8
	9	43.5	3.6	24	122.0
	9	30.5	3.1	19	82.1
	9	31.5	3.0	21	72.3
	9	32.5	2.5	21	65.9
	9	31.0	2.8	21	74.8
	9	30.5	2.6	21	56.6
	9	40.5	3.6	25	122.5
	9	31.5	2.8	22	80.3
	9	25.5	2.2	20	60.4
	9	38.0	2.5	**	69.2
	9	22.0	2.3	18	47.3
	9	33.0	2.2	18	69.0

Appendix A (Concl'd.)

Day	Stool Number	Shoot Height (cm)	Shoot Diameter (mm)	No. of Nodes	Total Leaf Area (cm)
234	9	23.0	2.0	18	57.5